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TECHNICAL REPORT ARTSD-TR-77002

LEVEL II

BEYOND THE STATE-OF-THE-ART
ILLUMINATION MEASUREMENTS

C. L. SMITH
D. N. EVERSICK

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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Transmissometer	In-line array													
Illumination	Field-of-view													
Candlepower	Automatic change-of-scale													
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <p>The invention of a direct method of obtaining candlepower has led to the development of a mathematical model of a simplified system for field testing illuminant items. In addition to obtaining the light intensity independent of the source distance, an innovation for assessing the atmospheric transmissivity is described. The light transmission is measured without employing special equipment other than that used for the basic candlepower measurements. The model configuration constraints are based on present field test practice.</p>														

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20. Cont'd

This technique will allow two or three people to set up and man a complete field test system. Test results which formerly required extensive data reduction and processing will be available on-site for instant readout. Besides increasing the reliability of data and on-the-spot readout, this system should reduce costs and generally enhance illuminant testing.

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SUMMARY

The system comprises a complete method for conducting field tests on illumination flares. The physical model (fig. 8) was selected for the general test requirements of artillery and aircraft flare tests. It is not specifically tailored to any individual test requirements. The physical test configuration can be optimized for specific test requirements while covering a specified flare drop area. In such cases, computer programs can be used to assess the accuracy of the configuration.

The cell's photometer reproducibility is a critical factor in obtaining accurate candlepower measurements. (Appendix B has the computer program for evaluating transmissivity error versus cell reproducibility for the configuration shown in figure 6.) Also the accuracy of obtaining candlepower is limited by the maximum field-of-view. The angle subtended by the cell's field-of-view should be kept to a minimum within test constraints. See appendix C for computer program to plot system error versus distance to the most remote cell.

The illumination falling on the cell is measured to the accuracy of the cell photometer itself, which will be as good as the system calibration. The accuracy of reading the candlepower will have a greater error because of the added effects of changes with distance and effective cell area vs angle. Candlepower reading will be limited to 10 to 20 percent for a practical system. Transmissivity measurements with a 2% photometer reproducibility will have less than 10% error.

There is also error associated with background illumination. Error caused by background illumination can be largely accounted for by measuring and subtracting from the test illumination levels because the flare subtends only a small part of the field-of-view angle of the cell. Even so, it is advisable to use a location and configuration having small illumination levels compared to the signal.

BACKGROUND

Candlepower measurements are not made directly, but are obtained by measuring the illumination and calculating the candlepower using the inverse square law. This requires that the distance between source and sensor be known with a degree accuracy. This has been the most difficult problem in the field testing of large flares because the parachute flares must be tracked as they are deployed and descend, drifting with the wind.

The results of tests of artillery- and aircraft-deployed illumination flares are reproducible when testing is conducted under controlled conditions. Test conditions are controlled by using tunnels or towers which are available from the tri-services and some contractors. These facilities are employed primarily in developing new systems. The typical information derived through testing is the flare's efficiency, intensity, burning time and spectral distribution of light in relation to the various factors affecting the intrinsic characteristics of the item as a light source. When deployed by aircraft or artillery, a descending flare produces spatial and time variations in ground area illumination.

One facility for conducting field testing is the Pyrotechnic Evaluation Range (PER) located at Yuma Proving Grounds (YPG). The PER records ground area illumination to preset levels, foot-candles. From this information, a computer is programmed to produce all required test data.

A major problem encountered in field testing is controlling or accounting for environmental factors affecting the test. Previous methods employed to overcome this problem have required many people to transport, locate, and man the equipment. The quality of the test data, which are often incomplete or unreliable, does not justify the cost of this method. For example, evaluating the flare's candlepower in the field requires that the flare's position be determined versus time. The PER uses three CINE theodolites for this purpose, and many people to operate them. Another field testing problem is correlating times and coordinating data systems with the firing of the flare. During field tests performed at Ft. Hood, manned photometers were deployed over large areas; stations were separated by thousands of meters.

New, ultrasensitive, prototype photometers were used with L-Band RF Links to record remote location information in a telemetry van. The flares were tracked by optical techniques. Typically, some data is lost

during tests of this kind because the position of the item is lost temporarily during its burning. Also, flares descending and traversing with the wind occasionally saturate near stations and produce weak signals at distant stations.

To evaluate the light source intensity with any degree of accuracy, the atmospheric transmissivity of the test range environment must be assessed. In the past, weather reports provided crude estimates of visibility limitations. Also, since the varying configuration of a flame produces a flickering, nonisotropic light, source intensity can be determined reliably only when it is derived through spatial integration of candlepower, i.e., average light intensity when viewed from all directions.

The method described in this report uses an array of highly sensitive photometers incorporating automatic change of scale circuitry and automatic calibration to operate without a man in the loop.

DEVELOPMENT

System development involves two innovations to the state-of-the-art of flare testing. The first is a method of determining candlepower of the flare item without knowing its position or distance. The second is a means of assessing the transmissivity of the atmosphere over the test area to an accuracy better than 10%. The candlepower measurement is corrected by the transmission factor to yield the true field candlepower of the flare. The photometers record ground illumination. All other parameters are derived through data processing. These measurements are taken in real time as the item burns and descends by parachute.

The photometers have a fixed field-of-view and a position that is determined by the system equations and mathematical model. A restricted field-of-view and optimum angle-of-look are required to reduce system errors caused by background illumination and field test configuration. The field-of-view for each cell will be designed through the use of a series of baffles to view only the region of operation of the item. The effects of background illumination will be further reduced by an automatic calibration and correction system.

Calibrating of the system is a three-step procedure. First, the optical equipment is calibrated with a laboratory standard. Second, equipment in the field is calibrated with an optical transfer standard. Third, the signal-conditioning electronics and RF link are electronically calibrated.

The field photometers consist of an ICI-Y photocell which is corrected to obtain spectral response equal to the average human eye, a filter, a cone, and electronics (fig. 1). A silicon photovoltaic barrier layer photocell is used for its stability and small temperature coefficient. The cell drives a low-noise operational amplifier which is used in its inverting mode to enhance the system's dynamic range. Operating the cell into an effective zero impedance extends the cell's linear range. Three operational amplifiers (G1 thru G3, figure 1) measure resolution and dynamic range. The automatic circuitry selects the appropriate amplifier and outputs data to a conventional telemetry system. The photometer output is transmitted via an L-band PCM/FM/FM RF link from each remote field sensor to a central recording van where the data are processed and recorded. To improve system accuracy each photometer has a pulse code modulator (PCM) which digitizes before transmission. The PCM word length is set to reduce quantization errors to meet system requirements. Parity is used to detect transmission link errors. Each photometer incorporates a voltage controlled oscillator (VCO) which contains photometer scale information. An automatic change of scale is used to improve the system dynamic range. The outputs of the PCM and VCO modulate the L-band RF transmitter.

The automatic circuitry selects the appropriate system gain to optimize the output data, provides scale information on a separate VCO channel, and assures data calibration by an automatic calibration interrupt.

The transmitted signals from each field photometer are received by an L-band antenna and receiver at the central receiving station (fig. 2). The receiver output is applied to two discriminators. One discriminator contains the illumination data, in PCM format, and the other provides the automatic range information.

The processor operates on both the data and scale information from each remote photometer and outputs to a visual display the real time illumination levels (E) for each remote site.

A simplified general field test configuration, using three remote photometers and a source flare, is illustrated in figure 3. D_1 , D_2 , and D_3 represent the distance from the source flare to each respective photometer with E_1 , E_2 , and E_3 representing the levels of illumination they receive. These illumination levels are transmitted to the central recording site and impressed on the input of the processor. At the beginning and at the end of the test, the processor calculates the transmissivity (T) from E_1 , E_2 , and E_3 . Using the transmissivity and any two of the illumination levels, the processor calculates the intensity of the source (I).

Candlepower Measurements

Candlepower is calculated from the difference of two photometer readings. A typical geometry is shown in figure 4. Photometers are located at fixed positions E_2 and E_3 with a fixed field-of-view and directed as shown.

This system uses an in-line array of two photometers to make the flare item appear as an isotropic radiator. Two photometers are placed in a line at a distance from the anticipated position of the flare's trajectory. Given these conditions, the candlepower of the test item can be determined by a relation of the two illumination levels recorded by the two photometers E_2 and E_3 and the fixed distance between them. This eliminates the need to track the flare and measures its distance, with respect to time, from the photometers.

Consider the simple case (fig. 5) where the flare (source) is at position 0. The expression for the illumination being seen by the photometers is:

$$E_3 = \frac{I}{D_3^2} \quad (1)$$

$$E_2 = \frac{I}{D_2^2} \quad (2)$$

$$D_3 = D_2 + d \quad (3)$$

To solve for the candlepower (I) of the flare, the following equations are used (distances D_3 and D_2 are unknown):

from equation 1

$$I = E_3 D_3^2 \quad (4)$$

from equation 2

$$I = E_2 D_2^2 \quad (5)$$

where

E = Illumination

I = Intensity of source in candlepower

D = Distance.

Then

$$E_3 D_3^2 - E_2 D_2^2 = 0. \quad (6)$$

Using equation 3 to eliminate D_3 ,

$$E_3 (D_2 + d)^2 - E_2 D_2^2 = 0. \quad (7)$$

Solve for D_2 using quadratic

$$D_2 = \frac{-d (E_3 + \sqrt{E_2 E_3})}{(E_3 - E_2)}. \quad (8)$$

Substitute D_2 to solve for I

$$I = E_3 (D_2 + d)^2 \quad (9)$$

$$I = E_3 \left[d - \frac{d (E_3 + \sqrt{E_2 E_3})}{E_3 - E_2} \right]^2 \quad (10)$$

Put in simplest form

$$I = \left[\frac{d}{\frac{1}{\sqrt{E_3}} - \frac{1}{\sqrt{E_2}}} \right]^2 \quad (11)$$

Therefore, knowing the illumination levels E_2 and E_3 and the fixed distance, d , separating photometers #2 and #3, it is possible to compute candlepower I .

This simplified case does not represent a typical flare field test configuration because the flare in the field test is not directly in line with the photometers. Flares are deployed to burn from a height of approximately 2,000 feet to 800 feet and then extinguish. Measurement accuracy is improved by aiming the cells to view this region of operation (fig. 4) optimizing the angle at which the light rays impinge on the cell. This angle is critical because if it is not optimum, it will reduce the effective area of the cell which in turn reduces the illumination level that the cell experiences. A light incidence angle of 10° off cell axis normal would cause an error as high as 4%. To partially compensate for this error, the cells will be aimed

at a point between the 800 ft and 2,000 ft elevation. For the test configuration of figure 4, cells E_2 and E_3 are set 9.93° and 7.25° , respectively, above horizontal.

The computer program in appendix A computes the expected accuracy of the system and the optical separation between stations E_2 and E_3 for the configuration inputted. For the test configuration of figure 4, the optical separation, d , is computed using equation (3):

$$d = D_3 - D_2 \quad (12)$$

where $D_3 = 11088.73$ ft

and $D_2 = 8121.58$ ft

then $d = 2967.15$ ft

This value of d applies only to the configuration described in this report. A new value of d would be computed when the configuration is changed.

Besides eliminating the tracking equipment and the additional people needed to set up and man the tracking equipment, this method simplifies the data recording and evaluation. With the old method, extensive data processing was required; with this system the data are processed while the test is in progress. The ground illumination, E_2 and E_3 , is being recorded and plotted in real time. The flare's intensity (I) is also being computed and plotted using the equation (11) and E_2 , E_3 and the system constant, d . This requires a data processor consisting of three integrated circuit chips for generating the flare's intensity in real time analog form. In actual field tests more than one array of two photometers may be deployed depending on test requirements. There are no stringent requirements on the photometer/receiving station RF link; L or S band telemetry transmitters have been used with FM/FM modulation. Depending on system accuracy required, either FM/FM or PCM/FM can be used.

Transmissivity Measurements

Transmissivity is calculated by finding the difference between illumination measurements. The difference between the two measurements in the array from the same source indicates the transmission of light on the optical path.

The system for measuring transmissivity uses highly sensitive photometers with automatic change-of-scale circuitry to extend the dynamic range without limiting instrumental accuracy. The in-line array of three photometers (fig. 6) yields a method of assessing the loss of light caused by atmospheric attenuation to within 10%. If a large flare is burned as shown in figure 6 before and after each test, the transmissivity of the test range environment can be measured. Figure 7 shows a typical test configuration.

The general expression for determining the intensity (I) of a flare with an in-line array of two photometers is

$$I^{\frac{1}{2}} = d / (1/\sqrt{E_2} - 1/\sqrt{E_1}) \quad (13)$$

where d is the known optical separation between sensors II and I, and E_2 and E_1 are the illumination levels (fig. 6). This general expression can be modified to include atmospheric attenuation by scaling the illumination levels as a function of T (transmissivity) and distance from source.

$$I^{\frac{1}{2}} = d / \left(1 / \sqrt{E_2 / T^D} - 1 / \sqrt{E_1 / T^{D-d}} \right) \quad (14)$$

A similar equation can be obtained using the illumination data from sensors II and III.

$$I^{\frac{1}{2}} = d \left(1 / \sqrt{E_3 / T^{d+D}} - 1 / \sqrt{E_2 / T^D} \right) \quad (15)$$

Eliminating I in equations (14) and (15) yields

$$\begin{aligned} & \left(1 / \sqrt{E_2 / T^D} - 1 / \sqrt{E_1 / T^{D-d}} \right) \\ &= \left(1 / \sqrt{E_3 / T^{D+d}} - 1 / \sqrt{E_2 / T^D} \right) \end{aligned} \quad (16)$$

By multiplying numerator and denominator by $1/\sqrt{T^D}$ and simplifying

$$\frac{2}{\sqrt{E_2}} = \frac{T^{d/2}}{\sqrt{E_3}} + \frac{T^{-d/2}}{\sqrt{E_1}} \quad (17)$$

Solve for T by changing variables and using quadratic equation.

$$T = \left(\sqrt{E_3/E_2} + \sqrt{\frac{E_3}{E_2} - \frac{E_3}{E_1}} \right)^{2/d} \quad (18)$$

The solution of T yields the transmissivity for the test range environment, which can be inserted in equation (14) or (15) along with the measured values of E_2 , E_3 , and the fixed value of d to obtain a more accurate field measurement of the flare candlepower. This system assesses the atmospheric transmissivity of the test range before a test is conducted. Test data are accurate to within 10%. Transmissivity tests are performed with the equipment provided for the basic illumination measurements, so the system is highly efficient and very economical.

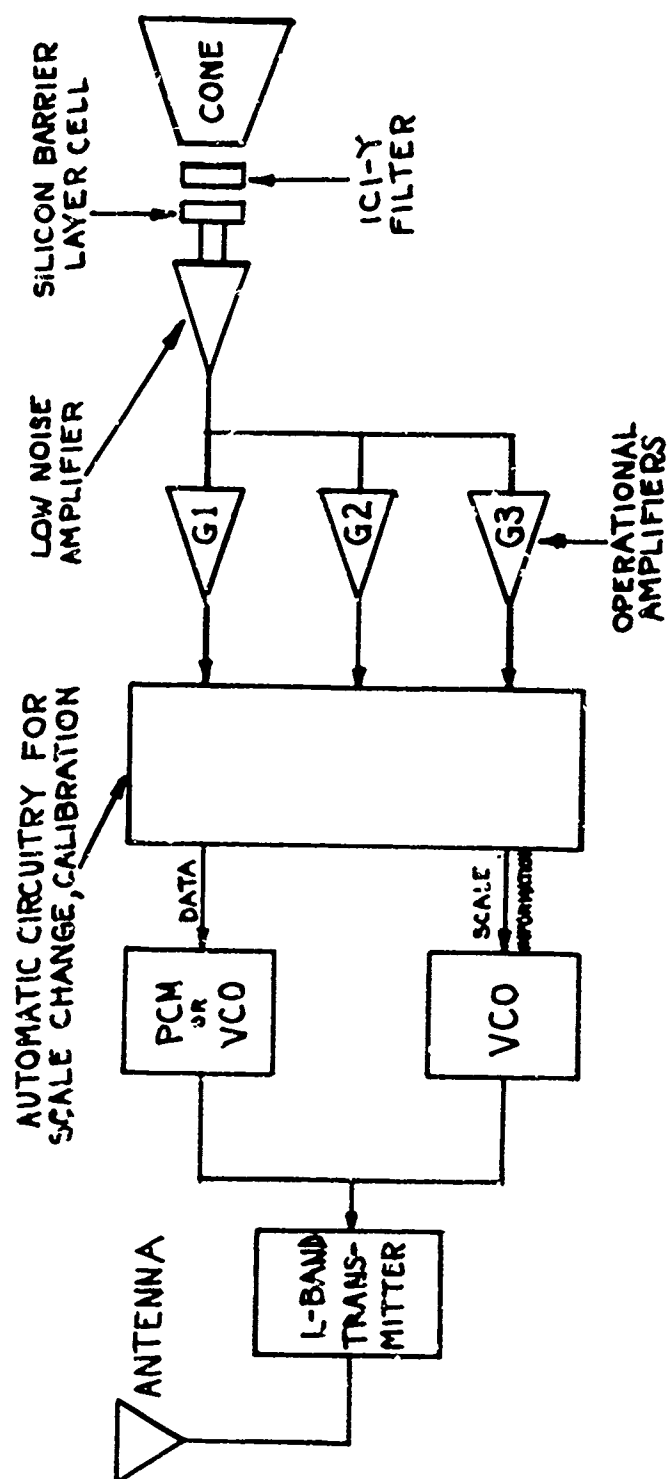


Figure 1. Field photometer block diagram

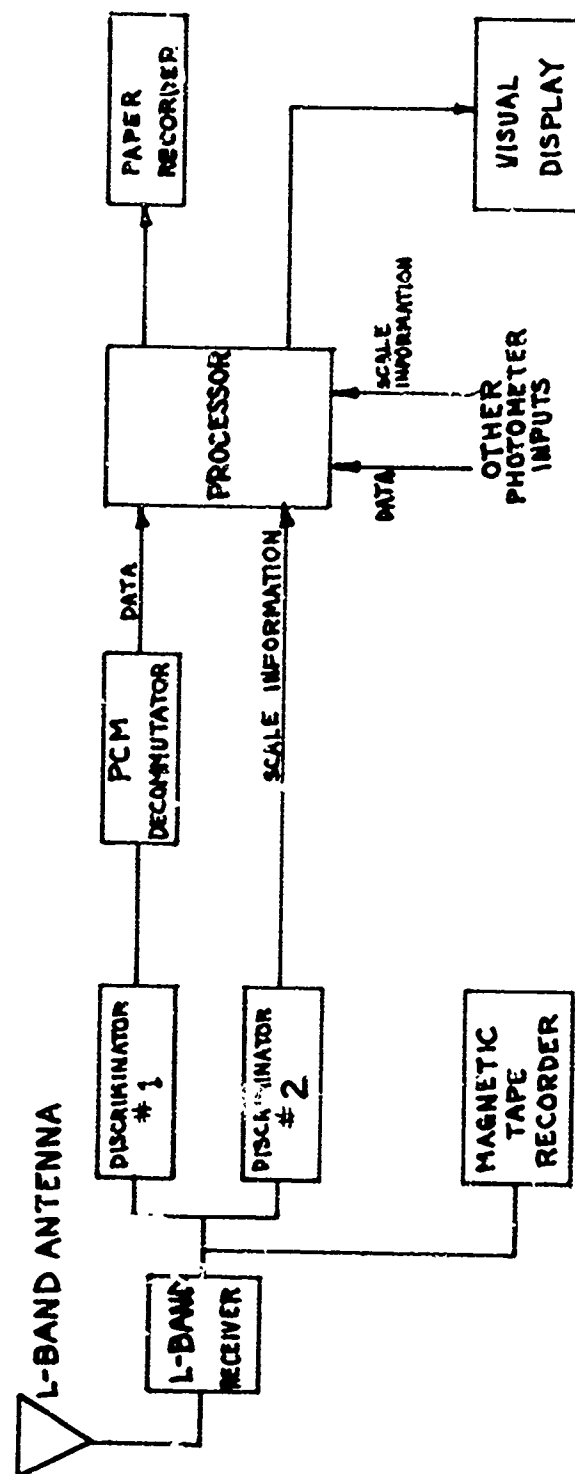


Figure 2. Receiving station block diagram (single channel)

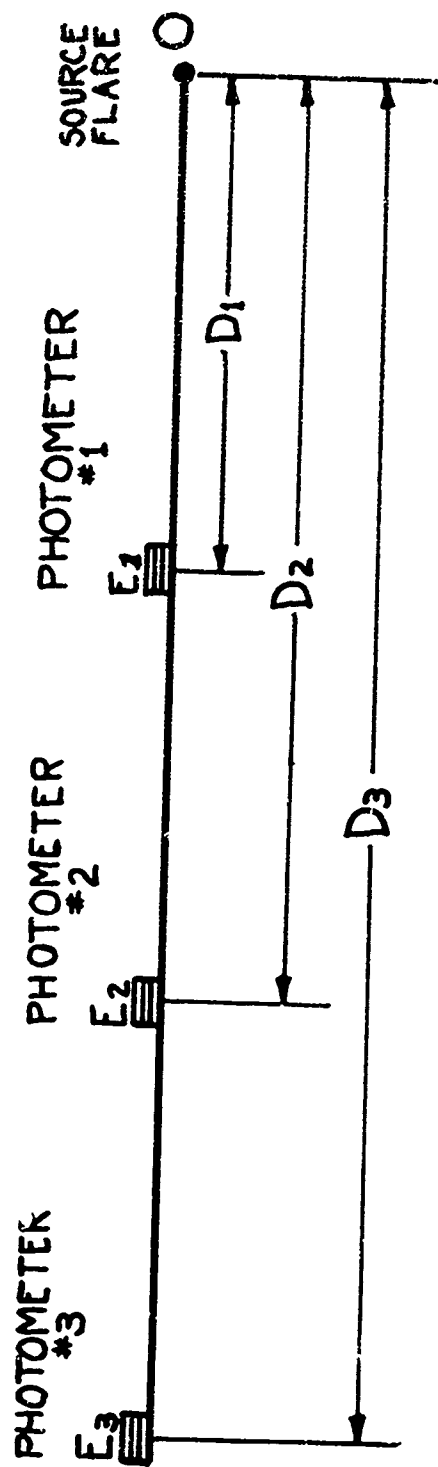


Figure 3. Simplified general test configuration

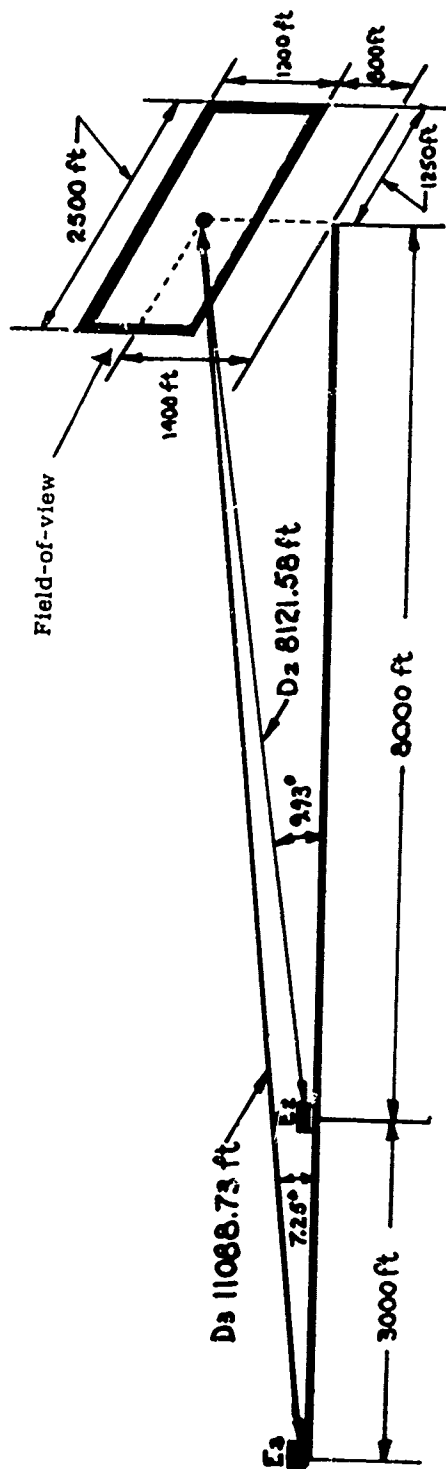


Figure 4. Test configuration for flare measurement

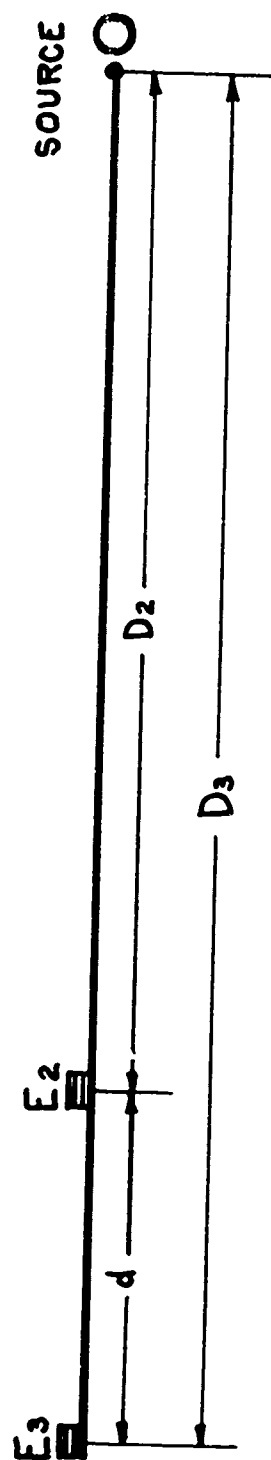


Figure 5. Simple test configuration

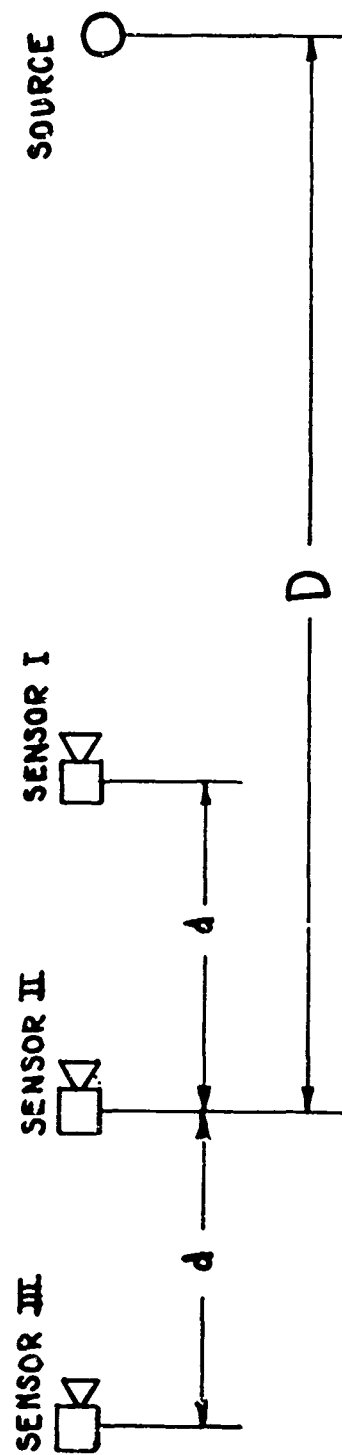


Figure 6. General test configuration

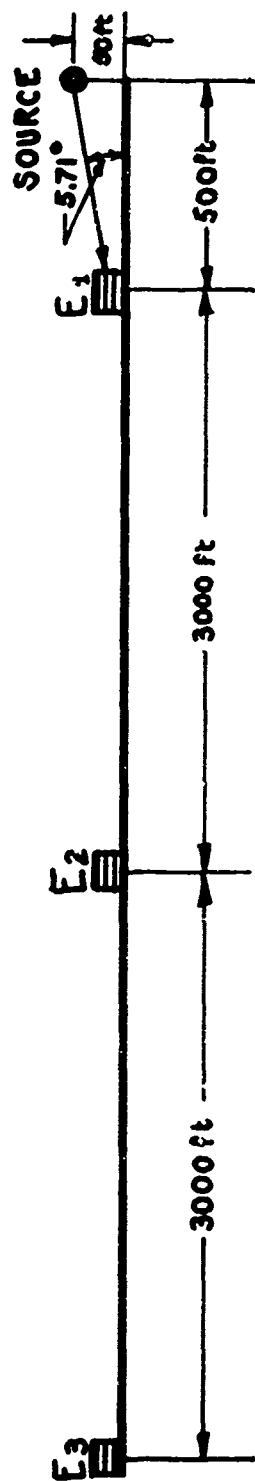


Figure 7. Test configuration for transmissivity measurement

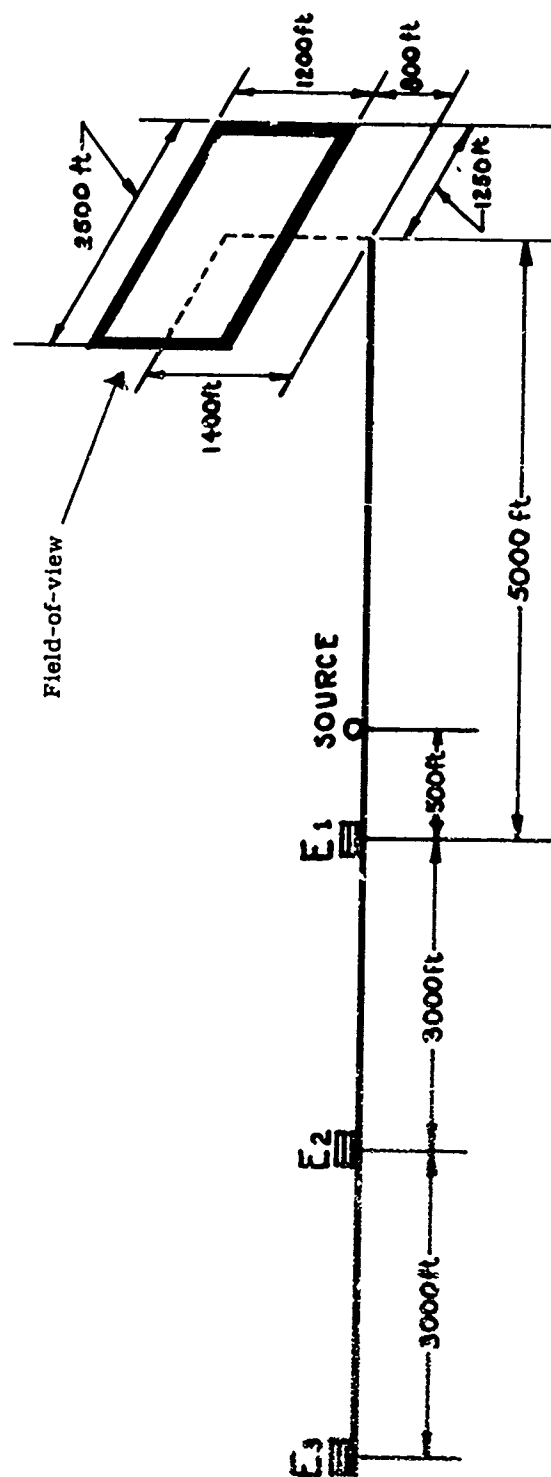


Figure 8. Typical test configuration

APPENDIX A

Program to Find Worst Case Error in Candlepower Calculations,
Neglecting Transmissivity from Test Configuration as Shown in Figure 4

```

1 REM --- APPENDIX A
2 REM --- TITLE - PROGRAM TO FIND WORST CASE FIELD IN
3 REM --- CANDLEPOWER CALCULATIONS, NEGLECTING
4 REM --- TRANSMISSIVITY FIELD TEST CONFIGURATION
5 REM --- AS SHOWN IN FIG. 4
10 PRINT "*****"
20 PRINT
30 PRINT
40 PRINT
45 PRINT "PRESS RETURN TO CONTINUE PROGRAM"
46 INPUT A
47 IF A<>0 THEN 570
50 PRINT "INTENSITY OF FLARE";
51 INPUT I
52 PRINT "MIDDLE OF CUBE (X-COORDINATE)";
53 INPUT X1
60 PRINT "ERROR OF CELLS IN DECIMAL FORM";
61 INPUT E
62 PRINT "CELL SEPARATION";
63 INPUT D
65 PRINT "PRESS 9 TO CHANGE VARIABLES, OTHERWISE PRESS RETURN"
67 INPUT J
68 IF J<>0 THEN 10
70 PRINT "DISTANCE IN X DIRECTION FROM FURTHEST CELLS";
71 INPUT X
72 PRINT "Y=";
73 INPUT Y
74 PRINT "Z=";
75 INPUT Z
80 LET D5=SQR(X1*X1+1.96000E+06)-SQR((X1-D)*(X1-D)+1.96000E+06)
81 LET T1=ATN(1400/(X1-D))
82 LET T2=ATN(1400/X1)
130 GOSUB 400
215 LET B=D
216 LET H3=H1
260 PRINT "INTENDED SEPARATION 'D' ="D5
270 PRINT "INTENSITY OF FLARE="I
280 PRINT "CELL ERROR="ABS(E*100)
300 PRINT "DISTANCE BETWEEN CELLS="B
310 PRINT "ERROR OF SYSTEM="H3
320 PRINT "LIGHT INTENSITY SYSTEM FINES="P
360 PRINT "-----"
370 GOTO 65
400 REM-----D=SEPARATION
402 REM-----D5=INTENDED SEPARATION
405 REM-----X,Y,Z=COORDINATES
410 REM-----I=INTENSITY
415 REM-----E=ERROR OF CELLS
420 REM-----SUBROUTINE TO CALCULATE ERROR
421 LET V1=SQR(X*X+Z*Z)
422 LET V2=ATN(Z/X)
423 LET V3=V2-T2
424 LET V4=V1*COS(V3)
425 REM-----H1=ERROR OF SYSTEM
426 LET V6=SQR((X-D)*(X-D)+Z*Z)
427 LET V7=ATN(Z/(X-D))
428 LET V8=V7-T1
429 LET V9=V6*COS(V8)
430 GOSUB 500
440 LET H2=H1
445 LET P5=P
450 LET E=-E
455 IF E<0 THEN
456 GOSUB 500
470 IF H1 >= H2 THEN 560
480 LET H1=H2
485 LET P=P5
490 GOTO 560
500 LET D1=(X-D)*(X-D)+Y*Y+Z*Z
510 LET D2=X*X+Y*Y+Z*Z
520 LET E1=(1/D1)*(V9/SQR(D1))*(1+E)
530 LET E2=(1/D2)*(V4/SQR(D2))*(1-E)
540 LET P1=D5/(1/SQR(E2)-1/SQR(E1))
545 LET P=P1*P1
550 LET H1=ABS(((P-1)/1)*100)
560 RETURN
570 END
READY

```

RUN

PRESS RETURN TO CONTINUE PROGRAM

?

INTENSITY OF FLARE?1000000

MIDDLE OF CUBE (X-COORDINATE)

?11000

ERROR OF CELLS IN DECIMAL FORM?.02

CELL SEPARATION?3000

PRESS 9 TO CHANGE VARIABLES, OTHERWISE PRESS RETURN

?

DISTANCE IN X DIRECTION FROM FURTHEST CELLS?11000

Y=?0

Z=?1400

INTENDED SEPARATION 'D' = 2967.157

INTENSITY OF FLARE= 1000000

CELL ERROR= .2

DISTANCE BETWEEN CELLS= 3000

ERROR OF SYSTEM= 14.29149

LIGHT INTENSITY SYSTEM FINDS= 1142915

PRESS 9 TO CHANGE VARIABLES, OTHERWISE PRESS RETURN

?9

PRESS RETURN TO CONTINUE PROGRAM

?9

STOP AT LINE 570

READY

APPENDIX B

Special Program for Finding Worst Case Transmissivity Error
vs Cell Reproducibility Using Configuration Shown in Figure 6

```

1 REM --- TITLE - SPECIAL PROGRAM FOR FINDING WORST CASE
2 REM --- TRANSMISSIVITY ERROR VS. CELL REPRODUCABILITY
3 REM --- USING CONFIGURATION SHOWN IN FIG.6
12 PRINT
13 PRINT
14 PRINT "          TRANSMISSIVITY PROGRAM I"
15 PRINT
16 PRINT
17 PRINT "INPUT THE FOLLOWING; T,H,E";
18 INPUT T,H,E
19 IF T<0 THEN 17
20 IF H<0 THEN 17
21 IF E<0 THEN 17
22 PRINT
23 PRINT
24 PRINT "          TEST CONFIGURATION"
25 PRINT
26 PRINT
27 PRINT "          T;"H"FT"
28 PRINT "          ..."
29 PRINT "          ..."
30 PRINT "          ..."
31 PRINT "          ..."
32 PRINT "          I--D3--I--D2--I-----DI-----I"
70 PRINT
71 PRINT
72 PRINT "T=";T;","CELL ERROR=";E
75 PRINT
80 PRINT "          D3 AND D2 MUST BE EQUAL"
85 PRINT
90 PRINT "TYPE 0 FOR D1,D2,D3 TO RESTART PROGRAM"
95 PRINT
105 PRINT "INPUT D1,D2,D3";
110 INPUT D1,D2,D3
111 IF D2<>D3 THEN 105
112 IF D1<0 THEN 105
113 IF D3<0 THEN 105
114 IF D1<>0 THEN 119
115 IF D3<>0 THEN 119
116 GOTO 10
119 LET R=0
120 LET L3=(D1+D2+D3)*2*H*H
130 LET L2=(D2+D1)*2*H*H
140 LET L1=D1*D1*H*H
150 FOR X=-1 TO 1 STEP 2
160 FOR Y=-1 TO 1 STEP 2
170 FOR Z=-1 TO 1 STEP 2
180 LET A=E*Z
190 LET B=E*Y
200 LET C=E*X
210 LET E1=100000./L1*T*(SQR(L1)/5280)*(1+A)
220 LET E2=100000./L2*T*(SQR(L2)/5280)*(1+B)
230 LET E3=100000./L3*T*(SQR(L3)/5280)*(1+C)
240 LET T1=SQR(E3/E2)
250 LET T2=SQR(E3/E2-SQR(E3/E1))
260 LET T3=(T1+T2)*(2/(D3/5280))
270 LET R1=(T3-T)/T*100
280 IF ABS(R1)>ABS(R) THEN 00
290 NEXT Z
300 NEXT Y
310 NEXT X
320 PRINT
330 PRINT
340 PRINT "-----"
350 PRINT "D1=";D1;"D2=";D2;"D3=";D3
360 PRINT "ERROR OF T=";R
370 PRINT "-----"
390 GOTO 95
400 LET R=R1
410 GOTO 290
420 END

```

APPENDIX C

Program to Plot System Error vs Distance to Farthest Cell

```

1  REM  APPENDIX C
2  REM  TITLE  PROGRAM TO PLOT SYSTEM ERROR VS
                DISTANCE TO FARTHEST CELL

```

```

LIST
3  LET G=1250
10  LET J=2000
15  LET E=100000.
17  LET M=-2.00000E-02
20  LET L=3000
25  DEF FNX(X)=(X-L)*2+G*2+J*2
30  DEF FNY(X)=X*2+G*2+J*2
35  DEF FNZ(X)=SQR((X-L)*2+J*2)
40  DEF FNV(X)=ATN(J/(X-L))-ATN(1400/(X-L))
45  DEF FNT(X)=FNZ(X)*COS(FNV(X))
50  DEF FNM(X)=SQR(X*2+1.96000E+06)-SQR((X-L)*2+1.96000E+06)
55  DEF FNS(X)=SQR(X*2+J*2)
60  DEF FNR(X)=ATN(J/X)-ATN(1400/X)
65  DEF FNQ(X)=FNS(X)*COS(FNR(X))
70  DEF FNP(X)=(E/FNX(X))*(FNT(X)/SQR(FNX(X)))+(1+M)
75  DEF FNO(X)=(E/FNY(X))*(FNQ(X)/SQR(FNY(X)))+(1-M)
80  DEF FNN(X)=(FNM(X)/(1/SQR(FNO(X))-1/SQR(FNP(X))))*2
100 DEF FNF(X)=(FNN(X)-E)/E*100
150 DIM Z(10)
400 LET R1=0
500 LET L1=0
600 LET Q1=0
700 PRINT "PLEASE INPUT THE FOLLOWING PARAMETERS:"
800 PRINT "LEFT X-ENDPOINT";
900 INPUT A
1000 PRINT "RIGHT X-ENDPOINT";
1100 INPUT B
1200 PRINT "X-SPACING";
1300 INPUT D
1400 PRINT "THE NUMBER OF UNDEFINED POINTS (IF NONE, ENTER 0)";
1500 INPUT N9
1600 IF N9=0 THEN 2100
1700 PRINT "ENTER THE UNDEFINED POINTS, FOLLOWING EACH WITH A RETURN"
1800 FOR K7=1 TO N9
1900 INPUT Z(K7)
2000 NEXT K7
2100 DEF FNG(X)=INT((Y7-L1)/D1+.5)+15
2200 LET L2=R2=FNFA
2300 FOR X=A TO B STEP D
2400 FOR I=1 TO N9
2500 IF X=Z(I) THEN 3100
2600 NEXT I
2700 IF FNF(X)>L2 THEN 2900
2800 LET L2=FNF(X)
2900 IF FNF(X)<R2 THEN 3100
3000 LET R2=FNF(X)
3100 NEXT X
3200 IF L2<0 THEN 3500
3300 LET R1=R2
3400 GOTO 3920
3500 IF R2>0 THEN 3700
3600 GOTO 3800
3700 LET R1=R2
3800 LET L1=L2
3900 LET D1=(R1-L1)/50
4000 IF L1<R1 THEN 4300
4100 PRINT "THIS IS THE FUNCTION Y=CONSTANT."
4200 STOP

```

```

4300 PRINT "THE MINIMUM VALUE OF THE FUNCTION IS";L2
4400 PRINT "THE MAXIMUM VALUE OF THE FUNCTION IS";R2
4500 PRINT "THE SPACING ON THE Y-AXIS IS";D1
4600 PRINT ""
4700 LET F=INT(-L1/D1+.5)+15
4800 IF A <= 0 THEN 5900
4900 IF A/D>6 THEN 5900
5000 LET Q1=1
5100 IF L1=0 THEN 5300
5200 PRINT TAB(F);""
5300 PRINT
5400 GOTO 7500
5500 FOR I=1 TO INT(A/D+.5)
5600 PRINT TAB(F);""
5700 NEXT I
5800 LET Q1=0
5900 FOR X=A TO B STEP D
6000 IF D<1.000000E-04 THEN 6300
6100 IF ABS(X)>1.000000E-05 THEN 6300
6200 LET X=C
6300 PRINT X.
6400 FOR P=1 TO N9
6500 IF K02(P) THEN 7500
6600 IF X00 THEN 7300
6700 FOR I8=1 TO 50
6800 PRINT "-";
6900 NEXT I8
7000 LET Q=1
7100 PRINT "Y"
7200 GOTO 9907
7300 PRINT TAB(F);""
7400 GOTO 9907
7500 NEXT P
7600 IF X<(X+D)>0 THEN 9600
7700 IF X<-D/2 THEN 9600
7800 FOR I=0 TO 50
7900 IF Q1=0 THEN 8200
8000 LET Y7=FN7(X)
8100 IF FN0(X)=1+15 THEN 8500
8200 IF I+15=F THEN 8700
8300 PRINT "-";
8400 GOTO 8800
8500 PRINT "-";
8600 GOTO 8800
8700 PRINT "0";
8800 NEXT I
8900 IF I+15=F THEN 9100
9000 PRINT "-";
9100 PRINT "Y"
9200 LET Q=1
9300 IF (Q1+1)=1 THEN 9907
9400 IF (Q1+1)=2 THEN 9500
9500 IF (Q1+1)=3 THEN 9916
9600 IF X<(X-D)=0 THEN 9809
9700 IF X <= D/2 THEN 7800
9800 LET Y7=FN7(X)
9900 IF FN0(X)>F THEN 9906
9901 IF FN0(X)=F THEN 9904
9902 PRINT ,AB(FN0(X));"";TAB(F);""
9903 GOTO 9907
9904 PRINT TAB(F);""
9905 GOTO 9907
9906 PRINT TAB(F);"";TAB(FN0(X));""
9907 NEXT X
9908 IF X >= 0 THEN 9917
9909 IF -X/D>6 THEN 9917
9910 FOR I=1 TO INT(-X/D+.5)
9911 PRINT TAB(F);""
9912 NEXT I
9913 LET Q1=0
9914 PRINT
9915 GOTO 7800
9916 PRINT TAB(F);""
9917 PRINT TAB(F);"X"
9918 IF Q=0 THEN 9908
9919 STOP
9920 PRINT
9921 PRINT
9922 PRINT
9923 FOR I=0 TO 50
9924 PRINT "-";
9925 NEXT I
9926 PRINT "Y"
9927 PRINT
9928 PRINT
9929 PRINT "
9930 STOP
9931 END

```

SINCE THE REAL Y-AXIS IS OFF THE GRAPH."

READY

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